Roe Herring Impoundment Research - Report on the 1983/1984 Studies

H. Kreiberg, J. R. Brett and A. Solmie

Department of Fisheries and Oceans
Fisheries Research Branch
Pacific Biological Station
Nanaimo, British Columbia V9R 5K6

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ABSTRACT

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A fourth and supplementary year of testing the impounding of maturing Pacific herring in floating netpens was carried out in a field location, northern Gulf Islands, British Columbia. The object of the current work was to examine improved alternative methods for transport of large quantities of live herring. Three methods were compared: towed seine-net transfer, towed semi-submersible live-barge, and a newly-developed towable netpen. Herring caught by purse-seine in late January 1984 were moved to the holding site established the previous year in Whaleboat Passage, and held through to one week post-maturation in late March 1984.

The towable netpen proved nearly as good as the live-barge and offered substantial improvement in survival to harvest over the towed seine. The findings of the previous 3 years on maturation and subsequent delay of spawning were confirmed; roe yield and quality assessments once again indicated a high quality for the impoundment roe. Yield of first-grade roe from an impoundment continues to increase for about 2 weeks post-maturation before peaking. A concluding section summarizes key aspects of the overall 4-year study. We consider the impoundment technique fully developed for adoption by industry.

Key words: herring, impoundment, survival, roe quality, maturation, live-transport, netpen, barge, seine

RESUME

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Des essais sur le terrain de mise en captivité de harengs du Pacifique en maturation dans des cages flottantes en filet, mouillées au nord des îles Gulf (Colombie-Britannique), ont eu lieu au cours d'une année supplémentaire, soit la quatrième. Ces travaux visaient l'évaluation de méthodes de rechange améliorées pour le transport de grandes quantités de harengs vivants. Trois méthodes ont été comparées: le remorquage d'une senne, d'une barge semi-immergeable et d'un nouveau parc en filet. Du hareng capturé à la senne coulissante à la fin de janvier 1984 a été transféré au site de stabulation établi l'année précédente dans le passage Whaleboat puis gardé en captivité jusqu'à une semaine après la maturation, à la fin de mars 1984.

Le parc en filet remorquable s'est révélé presque aussi efficace que la barge, en plus d'engendrer une nette amélioration de la survie jusqu'à l'exploitation par rapport à la senne remorquable. Les résultats recueillis au cours des trois années précédentes sur la maturation et le retard ultérieur de la fraie ont été confirmés; le rendement en rogue et les évaluations de la qualité ont à nouveau révélé une qualité élevée de la rogue obtenue en stabulation. Le rendement en rogue de première qualité fournie par des harengs en captivité continue d'augmenter pendant environ deux semaines après la maturation avant d'atteindre son maximum. Un résumé des principaux aspects de l'étude de quatre ans est présenté en conclusion. Selon les auteurs, la technique de mise en captivité est prête pour le transfert à l'industrie.

Mots-clés: hareng, mise en captivité, survie, qualité de la rogue, maturation, transport à l'état vif, parc en filet, barge, senne

INTRODUCTION

We found in our previous year's work (Kreiberg et al. 1984) that herring sustained injuries during towed-net transit to an impoundment site despite precautions and experienced handling, with subsequent heavy mortality. Our experience suggested that a netpen could be modified for transport of herring without severe injury. In the present work, we compare the transport methods of live-barging, seine-towing, and netpen-towing. Our main criterion of success was survival to harvest, followed by an analysis of the general practicality of each method. The previous year's work had demonstrated the suitability of the selected field site (Kreiberg et al 1984), and preceding years had established the basic principles of roe herring impoundment (Brett and Solmie 1982, Kreiberg at al. 1982).

As in all but the initial exploratory year, studies were carried out on a production scale, using commercial charter vessels, and relying on the cooperative efforts of experts for assessing roe quality and yield. As in other reports on this research, ton is used instead of tonne, because of the long experience of estimating catches in this unit. Brief mention is made of separate research at the Departure Bay fishfarm as it bears on previously reported work. For continuity, the reporting follows the form established in the previous reports, to which periodic reference is made. A brief summary of the present findings is first presented, followed by more detailed accounts and a general discussion.

SUMMARY STATEMENT

1) CATCHING AND TRANSPORT OF HERRING

A large school of herring near the impoundment site was fished by seine for each of the transport methods. The first suitable catch, estimated at 35 tons, was towed by seine 1.2 nautical miles to the impoundment on 29 January; this was followed by 23 tons on 30 January transported by towable netpen over 1.5 nautical miles. A barged load of 3.3 tons was also transferred on 30 January over 1.5 nautical miles. Sealions were a frequent nuisance during fishing operations.

2) SITE AND HOLDING FACILITY

Herring from the towed seine and the towable netpen were held separately in two 27.7 m x 9 m x 7 m deep knotless nylon netpens housed on a divided 30.8 m x 21.5 m float. Barged herring were held in a 7.5 m x 7.5 m x

6 m deep netpen and float attached to the main float. The site was monitored by a resident watchman for the duration of the experiment.

3) BASIC RESULTS

The 3 netpens were stocked to roughly equal densities approximating 8 kg/m^3 (0.5 lb/ft^3). All fish matured to GSI (♀)=25 (where GSI is the percent body weight comprised of gonads), and had not spawned at the time of harvest, 1 week after maturity (which for practical purposes occurred on 16 March 1984). Survival was 99.6% for the barged fish, 97.0% for the towable netpen, and 79.6% for the towed seine. Maximum practical tow-speeds used for the 3 methods were: 3.5 knots (barge), 0.5 knot (netpen), and 0.2 knot (seine). There were no outbreaks of disease or other modifying factors.

CATCHING AND TRANSPORTING HERRING

1) CHARTERS

Catches were made by the seiner FISHER LASSIE under Vivian Wilson, for both the seine towing and the towable netpen. Catching for the barge transfer was done by the seiner MARY ROBERTA under Richard Johnson, with the live-barge LIVEWAY (described in Brett and Solmie 1982). Both charters required proven abilities in live transport of herring.

2) CATCHING AND TRANSPORT

For the duration of fishing activities, a school of 7-10,000 tons of herring was lying off Pylades Island about 1-1.5 nautical miles from the impoundment site. All catches were made in the same location and were all drawn from the one concentration of herring.

Seine-towing

Fishing operations began on 29 January. A dawn set yielded mainly small herring, and was released. A second set after dusk was also released due to small fish. A third set yielded large fish and a roughly equal sex ratio, hence was kept.

For towing, a section of the seine corkline was spread the full length of the seiner and tied off, with 2 100-kg iron rings suspended deep in the net off the side of the vessel. This arrangement countered the tendency for a seine under tow to take on a tear-drop profile with the fish crowded into a bag at maximum distance from the seiner. The common technique of one seine skiff towing the seiner broadside with the net trailing was used. A second skiff circulated in the wake of the tow, keeping sealions away and periodically checking for incidence of dislodged herring scales to ensure that the fish were not being excessively damaged.

The herring 'followed' or swam with the direction of tow very well; the estimated catch of 35 tons was moved 1.2 nautical miles at a speed over the bottom of 0.2 knot. The entire catch was loaded into the netpen at the site by making a temporary submerged gate. For this, the topline of the netpen was slacked off, allowing some of it to be pulled under the float and laced to a section of corkline. The temporary joint was sunk with weights, and as the seine was drummed aboard, the fish were induced to swim through the gate into the netpen. Subsequently, when the herring had settled down, portions of the impounded catch were released over the top of the netpen, so as to reduce tonnage to match the towable netpen group and cull out injured and small fish.

Towable netpen

On 30 January in the early evening, a set was made within a cable or 2 of the previous night's catch towed by seine. The fish were sampled and deemed acceptable, and the supporting research vessel CALIGUS brought the empty netpen alongside the seine. For travelling empty, the pen web had been pulled up on the float, and required 30 minutes to re-rig. Loading in the usual submerged-gate fashion took less than 1 hour, following which the pen was pushed back to the holding site by the CALIGUS. A course change to avoid an adverse tidal stream increased the distance slightly to 1.5 nautical miles, which was traversed at a speed of 0.5 knot. A 100-watt underwater light hung off the bow of the CALIGUS was effective in keeping the fish out of the aft end of the netpen. The catch of approximately 22 tons swam in the appropriate direction at all times, remaining concentrated in the bow end of the netpen and at times filling the bow 'V' solidly. At the site, the fish were transferred by 'swimming' to their holding pen, beside the seine-towed group. None were lost or released.

Live-barge

The equipment and methods used in barging have been described in an earlier report (Brett and Solmie 1982). Fishing was carried out on the night of 30 January, alongside operations for the towable netpen. The second set yielded acceptable fish, and a light load estimated at 3.5 tons was transferred to the barge. Transfer, spillage of the balance of the set, and picking up the barge took approximately 1 hour. The actual tow itself lasted about 25 minutes, covering a distance of 1.5 nautical miles at a rate of 3.5 knots. The small netpen was then loaded with barged herring to a density of about 8 kg/m^3 (visual estimate) to correspond to the larger netpens.

The main points of the 3 methods of herring transport are summarized in Table 1.

SITE AND HOLDING FACILITY

1) SITE SELECTION AND DEVELOPMENT

Whaleboat Passage was the impoundment site selected for the comparison of transport methods. Site criteria and the location have been described previously (Kreiberg et al. 1984).

Floats and netpens

Herring from the towed seine and the towable netpen were held separately in two matched 27.7 m x 9 m x 7 m deep netpens on a longitudinally divided 30.8 m x 21.5 m Topper float (T-23-F design specification). A smaller 10 m x 10 m float housed the barged herring, in a 7.5 m x 7.5 m x 6 m deep netpen.

At Nanaimo, the floats were broken down into towable sections. Both floats were towed to Whaleboat Passage by the research vessel CALIGUS, which acted as a support vessel for field site development and netpen towing. The floats were reassembled and moored near the southeast side of Whaleboat Island. The method for mooring the netpens has been described previously (Kreiberg et al. 1984). The smaller netpen was secured to the larger at the northwest corner using 12 mm chain. A three-log breakwater was anchored at the southeast end of the large pen to dampen most incoming chop.

The netpens for housing the 3 groups of herring consisted of: a) an outer predator net made from salmon seine bunt or 75 mm trawl web, and b) the main netpens, constructed from soft knotless nylon web with a 22 mm stretched mesh measurement. The suspended weights for maintaining the box-like shape of the main netpen also supported the shape of the predator nets, ensuring a space between predator and holding nets. More details on pens, nets and rigging are found in Kennedy (1978) and Kreiberg et al. (1982,1984).

2) TOWABLE NETPEN

A major objective of the present work was to develop an improved method for the transport of live herring. Simple pre-season trials led us to the conclusion that a netpen could be modified easily for effective transport of fish. In brief, our findings were that herring towed and handled better by night than by day; an underwater light-source produced a clear avoidance

response, hence could be used to herd fish; the forward entry of a netpen could best be improved by creating a dynamic bow; and pushing the pen was preferable to towing it astern or alongside.

The dynamic bow for the netpen was formed by hanging a 100-kg iron ring deep in the middle of the forward end, and slacking off the downhaul line to each forward bottom corner. Underway, the corners folded back due to drag, while the weight was displaced very little, creating a V-shaped entry (Fig. 1). This approach proved both easier and more effective than others tried or considered, e.g. polyethylene skirts, countering all drag effects with weights, or adding on an actual bow section.

The Topper 30.8 m x 12 m single netpen float was modified to provide additional strength for towing purposes by: a) a 610 mm x 101 mm x 9 mm iron corner bracket that replaced all existing 177 mm x 152 mm x 9 mm corner brackets, b) a diagonal reinforcement frame constructed of 63 mm x 9 mm angle iron which was attached to the ungated end of the float with galvanized bolts running through the deck, stringers and sleepers (see Fig. 1-A), and c) the removable gate at the opposite end being fastened securely into position with 75 mm x 203 mm stringers and galvanized bolts to existing frame stringers.

Log-boomers use very long tow-lines to reduce propellor-wash effects when towing booms astern. Hence, we assessed various other positionings of the propelling vessel with respect to the netpen. The combination proved easily most effective with the vessel pushing at the mid-point of the aft end of the pen. A small fender of old tires protected metal and wood, and crossed bow-lines and stern-springs from boat to float were rigged in the manner shown in Figure 1-C. Diagonal corner-bracing reinforced the pen, and a soft fine knotless mesh liner was installed inside the aft end of the netpen, for the protection of fish washed up against it by the forward motion. In practice, the sound of the pushing vessel tended to keep herring toward the bow end of the netpen, as did the underwater lamp, suspended behind the netpen shining forward. Save for the upgrading of the netpen trim-anchors to 100 kg at all 8 perimeter positions, and the addition of several weights to keep the aft end from billowing up, no further alterations were made to convert the netpen for towing.

Two problems with handling of the towable netpen were noted. While towing the empty float and netpen astern, water pressure built up inside the stern end causing added stress to this section; additional bracing as installed at the bow was needed. As well, during towing empty to the location of the herring set, the pen web had been pulled up on the decking while still rigged to the weights hanging below. In transit, the weights twisted, fouling the downhaul lines, and causing some difficulty and delay in tranferring the fish to the holding pen at the site. The weights had been left lowered as it would have taken too long to re-rig the pen at the catching site using winch power from a support vesssel. Improved netpen handling methods will be covered in a forthcoming Industry Report now in preparation.

HANDLING OF FISH

Procedures used in the present work for fish transfers, removing samples and mortalities, and culling of excess or unwanted herring, have all been described in earlier reports on this investigation (Brett and Solmie 1982, Kreiberg et al. 1982,1984). On the basis of our work to date we have noted that herring handle more readily by night than by day. Similarly, we have noted a general increase in 'restlessness' of impounded herring as their maturation date approaches, making them more difficult to handle.

ENVIRONMENTAL CONDITIONS AND MEASUREMENTS

1) TEMPERATURE (Table 2, Figure 2)

Water temperature was recorded daily at noon from a sample taken at about 2 m depth, for the duration of the impoundment. Weekly mean temperatures over the period 29 January to 23 March varied little, rising fairly steadily from an initial 8.0 C to a final 10.0 C. The degree-day total for the duration was 517.0. In 1983 at this site, a shorter impoundment term logged a total of 410.8 degree-days; for the equivalent period in 1984 the total was 440.5.

2) SALINITY (Table 2, Figure 2)

Surface water salinity rose slightly in the early weeks of the impoundment, then levelled off for the latter half of the 53-day term. The mean for the duration was 31.2 ppt $\pm$ 0.6 SD, up from the mean in 1983 of 26.9 ppt $\pm$ 0.3 SD.

3) SITE SUITABILITY

The Whaleboat Passage site had proven to be a good impounding location in the previous year's work. No exceptions developed in 1984. While groups of up to 70 sealions circled the netpens immediately after loading, they persisted only a few days in the face of efforts to drive them off. Once again, the overall security of the site was much enhanced by having a caretaker present round the clock.

Shortly before the netpen herring were due to mature, a spawning of wild herring several miles upstream of the tidal ebb appeared to cause the pre-spawning behavioral stages of 'rising and milling' and (to a much lesser extent) 'substrate testing' of the netting as described in Stacey and Hourston (1982). However, with the reversing of the tide, the herring resumed normal schooling, no spawning having taken place.

STOCK CHARACTERISTICS

A summary of the vital statistics of the 3 netpens of herring is given in Table 3. The percent immatures ranged from a high of 8 in early sampling to 0 in the last 4 weeks of samples from all 3 groups. In the case of the seine-towed lot of fish, some of the reduction was due to intentional culling, however we can attribute no clear cause to the reduction in immatures in other lots. Herring graded as immature had gonads too small to permit sexing by eye, hence would not be expected to mature within the year.

From scale readings of all samples, the age class breakdown was:

Year	2	3	4	5	6	7	8	9
%	4.1	21.1	34.4	23.8	11.2	3.9	1.1	0.1

(A fish of age 2 would be in the second year of its life, i.e., 1+. Scale samples were taken in February and March, 4-10 weeks before herring enter a new season of growth)

COOPERATIVE STUDIES - ROE QUALITY, YIELD

Sampling for roe quality and yield was carried out on 3 dates, using approximately 30-kg samples. Roe was processed by the freezing method, and subsequently graded. The proportion of unripe roe decreased from 97% on 28 February to 1% on 22 March. By that date, 96% of the roe was graded as normal, i.e., mature with no sign of sponginess, fragility, or other drawbacks. The yield of roe totalled 30.2% of the weight of females, consistent with values observed in previous years (30.5% in 1983, 31.4% in 1982). Criteria used in grading roe are given in Appendix 1.

RESULTS AND DISCUSSION

1) CURRENT YEAR

Plan

With the emphasis of the 1984 work on methods of transport, there was no intent to hold the herring longer than a week post-maturation, to confirm the previously demonstrated delay of spawning phenomenon. As well, with an extensive test marketing and economic analysis already completed (noted in Kreiberg et al. 1982), the herring were not test-marketed.

Transport methods comparison

We have treated the barging technique as a live-transport reference standard in the present work. Our experience in the past 4 years of impounding operations has led us to expect very high survival rates using barges for transport, and we consider it unlikely that the method could be improved significantly in this respect (the method is described in Brett and Solmie 1982, and Kreiberg et al. 1982,1984). However, the capital cost of even a small barge can be substantial, and presently available barges can safely carry only small 6 to 8-ton loads. These limitations contributed to the emphasis of the present work on developing the towed netpen as a satisfactory alternative method of transport.

Survival to time of harvest for the 3 methods of transport tested was: seine-towed 79.6%, towable netpen 97.0%, live-barge 99.6%. From cumulative mortality curves (Fig. 3), it is clear that the towable netpen gave good results, comparable to the live-barge. The improvement in survival over the towed-seine method is significant at the probability level $P < 0.001$ (from slope comparisons of log-transformed cumulative mortality curves). Our result for seine-towing is consistent with the range of herring survival noted in the spawn-on-kelp industry, 60-79% (Shields and Kingston 1982). Seine-towing is the predominant transport method used in that industry, although it should be noted that spawn-on-kelp operators usually impound their herring for only 2-3 weeks at most, as opposed to the 8 weeks in our study. The survival result for our seine-towed herring is based on biomass after culling of injured and small fish immediately following delivery. Inclusion of the culled fish would likely have further reduced the survival result.

The principal cause of death in transported herring appeared to be physical damage aggravated by stress. Most mortalities from seine-towing could be ascribed to damage caused by the seine, either simple scale loss, or scale loss and damage to underlying skin and flesh. There was no indication of diseases, and very little incidence of secondary causes of mortality, e.g., wound infection. We conclude that the main reason for the success of the towable netpen was the reduction in fish contact with the confining web. While underway, the netpen was closely monitored; during the entire passage, only 2 small 'boil-ups' took place. It is in boil-ups that

fish damage occurs, as the mass of disturbed fish contacts the mesh of the moving web around them. The presence of the soft transport liner at the aft end of the pen helped to minimize damage from boil-ups.

Advantages of the towable netpen include increased cost-effectiveness over a live-barge resulting from its higher capacity and dual use as a fixed impoundment. As well, it has a much greater range of fishing operations than the towed seine, and twice the speed. The structure of the netpen provides 'elbow-room' for the herring, so the netpen can be anchored and left for a period once loaded, e.g., if stemming a tide. Similarly, if the tow extends into daylight hours when wild herring normally descend into deep water, it may prove desirable to break off towing until dark, to minimize stress. Again, the netpen could simply be anchored briefly. From a practical standpoint, converting a standard holding pen was easily done by 2 or 3 persons, and loading it at the time of capture was no more troublesome than readying a seine for towing. Sealions would likely not harass a moving netpen by surfacing for air while under the mesh, as they do with a seine.

Two constraints on the towable netpen concept are the geometry of the pen, and the maximum swimming speed of herring. While a long rectangular pen such as we used was easy to modify for transit, a square pen such as the traditional boom-log and seine-web enclosure would not lend itself as well to the suggested changes. The success of the method hinges upon maintaining as much of an overall shape as possible, to avoid compressing the fish into a small space touching the web. Studies carried out as part of our impoundment research have established the maximum continuous swimming speed of Pacific herring at about 1.1 knot. While further increases in the top speed of a moving netpen could likely be achieved by increasing the mesh size, 1 knot would in any case represent the upper limit.

It would be possible to interpret our results as a negative comment on seine-towing as a transport option. More correctly, the results illustrate the point that seine-towing is not as generally applicable to site and situation as are the other methods discussed. Under conditions of proximity to holding site and favorable tidal flows, seine towing can well be the most cost-effective way of transferring fish. One of us (Kreiberg) has observed seine-towing operations carried out by skilled handlers of live fish where it was most unlikely that any improvement could have been conceived. Significantly, these operations were carried out at an ideal site; herring were seined within a half-mile of the impoundment, and the catching was timed to take advantage of a tide-stream back-eddy which helped to move the loaded seine to its destination. The towing skiff did little more than maintain the form and direction of the seine.

Progress of maturation

The GSI was tracked by weekly sampling of at least 50 fish. Initial GSI was about 15 for both sexes, and rose steadily for the next 40 days. Levelling off, i.e. maturation, occurred for all 3 pens, males and females, at the same time, at about 25 (♀) and 21 (♂). Figures 4 and 5 show the pattern of increase for GSI. No spent fish were found in the samples before the end of the experiment.

Prediction of GSI development

As shown in our earlier work (Kreiberg et al. 1982), maturation date could be predicted well in advance by linear regression. We used an initial sample and the pooled regression on previous years, $y = 8.2 + 0.22x$ ($r = 0.92$) to predict maturity (GSI = 25) on 16 March 1984. From analysis of the 1984 data, the actual date was 15 March, from the regression line $y = 5.9 + 0.25x$ ($r = 0.92$). Thus, the prediction was as close as may be expected. It should be noted that maturation date in a group of herring may vary between individual fish depending on size and other factors. Hence, 'maturation date' as we use it merely describes the expected date at which the mean rate of gonad increase in all the fish in a netpen levels off. It is essentially a practical measure.

Biomass estimation

In the continued absence of accurate objective means of estimating catch, we used visual estimates as in previous years. Our error margin was reduced to about 12% (down from about 25% the year previous), reflecting the value of experience in estimating with the large netpens. Biomass could be estimated with greater accuracy in the case of the smaller netpens.

Sea-lion interference

The use of underwater sound has been suggested as a means of sealion repulsion, and has been tried with little success in other parts of the world against marine mammals interfering in fishing operations. In the present work, we used an underwater playback unit rated at 50 watts RMS, to play high quality recordings of 'transient' killer whales' hunting calls. While the playback appeared to have some effect, e.g. causing the sealions to group together, cluster near kelp-beds etc., they remained in the immediate area. We monitored underwater sound levels with hydrophones. At such relatively low power level, and due to the efficiency curve of the speaker being weak in the mid- and high-range zones, we were not impressed with the sound levels achieved. It appears that the expense and effort of achieving a suitably high level of underwater sound rules it out as a practical option.

Spawning releaser studies

Work was begun in 1982 to find methods of inducing spawning in impounded herring. In the current work, we presented kelp spawning-substrate to groups of herring at various times post-maturation, aided by small quantities of spermiated milt added to the surrounding water. While a variety of combinations were tried, and successful spawnings were noted at 3 weeks post-maturation, our results are preliminary and require corroboration. The studies are expected to continue in spring 1985. Results of a successful trial in March 1984 of several pituitary hormones for accelerating pre-spawning development in herring will be published separately.

2) ROE QUALITY AND YIELD

Analysis of roe quality over the past seasons indicates that while roe is acceptable for harvest on the date of maturation (the date after which the GSI no longer increases), the yield of both No.1 and combined No.1 + 2 grade roe continues to increase, reaching maximum yield at about 14 days post maturation, as shown in Figure 6. The rate of change is small on either side of the curve near the maximum point, and can be interpreted as permitting harvest of acceptable roe over a 4-week period. In nature where spawning normally occurs as fish become mature, commercial fisheries attempt to harvest roes at their maximum size before actual spawning. It is a common occurrence to have both spent and still-maturing roes in a commercial catch. By impounding herring early the problem of spent fish is avoided. Slower-maturing fish catch up to the main group over a period of days following the peaking of mean GSI. The effect of delaying harvest until the point of maximum yield may be expected to increase the harvest of No.1 roe by up to 17%, given that the catch is more or less typical of the seine fishery, i.e., some variation in size and maturity of the females. A hypothetical example is worked out in Appendix 2. It is important to note that the total roe weight does not increase after the maturation date; it is the quality of the roe that increases. The curves for roe yield in Figure 6 were derived using a non-linear quadratic equation (Schnute and McKinnell 1984). A table of values used to plot the curves is given in Appendix 3.

CONCLUDING COMMENTS

This report brings to an end the current research effort in sac-roe herring impoundment. Our main findings for the 4 phases of an impoundment operation are:

Capture: chartered commercial seiners were used. Herring must be handled gently and efficiently, a knotless bunt in the seine being an asset. Delays result in mortalities. Bycatch was minimal except for sealions, which can cause problems.

Transport: three methods were examined. Towing the herring-filled seine is unsuitable for distances much over 1 nautical mile, and success depends on favorable local conditions. A floating netpen can be modified easily for transport over greater distance, and with suitable mesh and handling affords low risk of tranport mortalities. A semi-submersible live-barge gives best results and greatly extends the range of operations; losses may be expected to remain well below 5%. In any fish transfer, it is vital to 'swim' the fish, as brailers and fish-pumps cause too much descaling and stress.

Holding: pens as large as 28 m x 9 m x 7.6 m deep (90' x 30' x 25') have been used for holding up to 35 tons of herring. The nets are purposely allowed to foul, thereby inhibiting early spawning. Density should not exceed 16 kg/m^3 (1 lb/ft^3) for 4 weeks holding, or 8 kg/m^3 for terms exceeding several months. Roe yield is not improved by feeding or cover. Once mature,

herring delay spawning for some weeks, as much as 7 or 8, while roe yield remains high for at least the first 3 to 4 weeks. Quality of roe continues to improve for about 2 weeks post-maturation. Capture as early as 10 weeks, and as late as 4 weeks before maturity, does not affect roe yield. The time of maturation can be predicted accurately by early sampling. Disease was experienced only once in 4 seasons.

Harvest: ripe herring with few or no immatures present are available over at least a 3-week harvest period. Research herring were sold by auction to a commercial processor, and were well-received. A benefit-cost analysis carried out by an economist indicates potentially very favorable prospects for sac-roe impounding depending on the source of herring, i.e., fished vs unfished stocks (in Kreiberg et al. 1982).

While there undoubtedly will arise new questions once commercial operations begin, there are at present no outstanding biological or technological problems blocking development. We consider the method ready for transfer to production.

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The weekly sampling and maintenance of the herring ponds was mostly done by Robert Kennedy, Kevin Hansen, Peter Bentley, and Susan Hansen, for which conscientious assistance we are grateful.

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Table 1. Comparison of 3 methods for transport of live herring to the Whaleboat Passage holding site.

	Barge	Netpen	Seine
Weight of herring (tons/trip)	3.3	23.0	35.0
Density in transit (kg/m^3)	22.2	9.4	N/A
(lbs/ft^3)	1.4	0.6	N/A
Distance covered (naut. miles)	1.5	1.5	1.2
Speed over bottom (knots)	3.5	0.5	0.2
Tow duration: load,rig (hours)	1.0	1.5	0.5
transit (hours)	0.4	3.0	6.0
Survival to 8 weeks (%)	99.6	97.0	79.6

Table 2. Weekly records of average environmental conditions monitored at the impoundment site, 1984. Readings were taken at about 2 m depth.

Week	Temperature (C)	Salinity (ppt)
Jan 29 - Feb 4	8.0	29.9
5 - 11	8.3	30.7
12 - 18	8.9	31.7
19 - 25	8.6	30.6
26 - Mar 3	8.8	31.6
4 - 10	9.3	31.7
11 - 17	9.6	31.6
18 - 24	10.0	31.7
Mean	8.9	31.2
SD	0.6	0.6
SE	0.2	0.2

Table 3. Vital statistics of herring impounded at Whaleboat Passage site, 29 January to 22 March 1984, as determined by weekly sampling.

	Pond 1	Pond 2	Pond 3
Mean length, mm	216.8	205.9	204.3
Mean weight, g	138.2	116.3	115.9
Percentage females	42.0	46.5	40.1
Density (kg/m^3)	7.8	9.4	9.0
(lbs/ft^3)	0.5	0.6	0.6
Survival to maturity	79.6	97.0	99.6
GSI(♀) at maturity	27.4	25.5	24.6

Pond 1 - seine-towed

Pond 2 - towable netpen

Pond 3 - live-barged

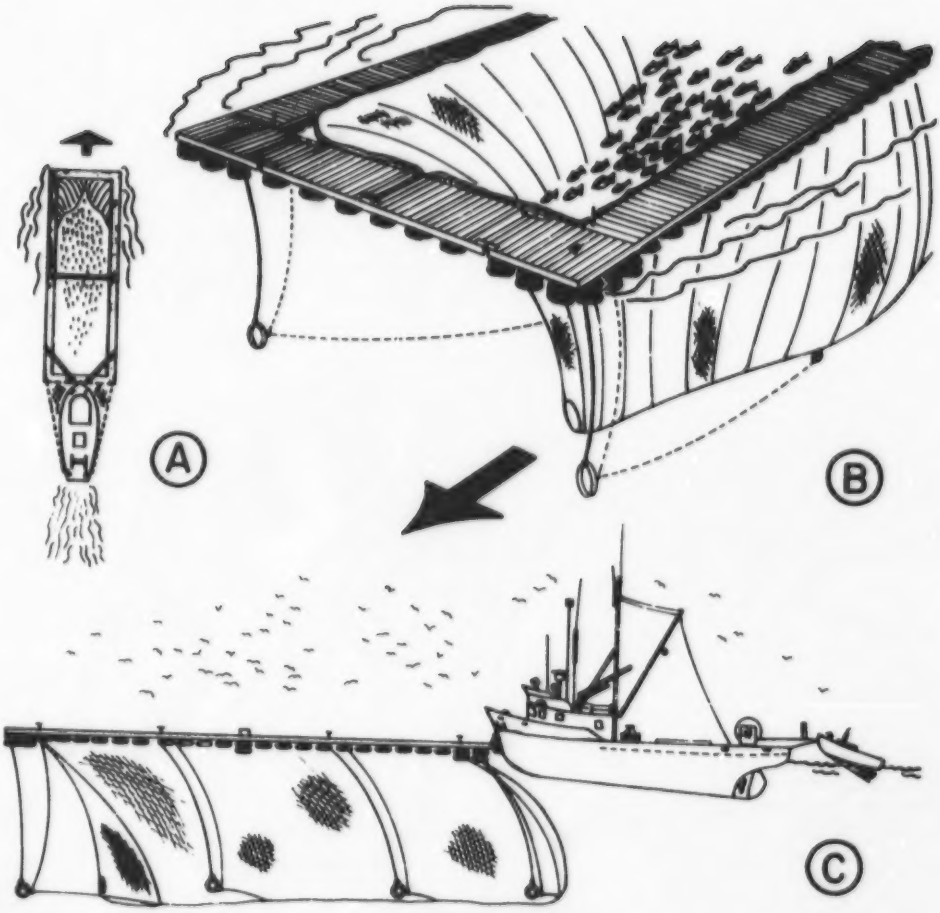


Fig. 1. The PBS towable netpen A)Top view, spring lines for pushing, frame reinforcement B)Netpen under way showing dynamic bow details C)Netpen under way, side view.

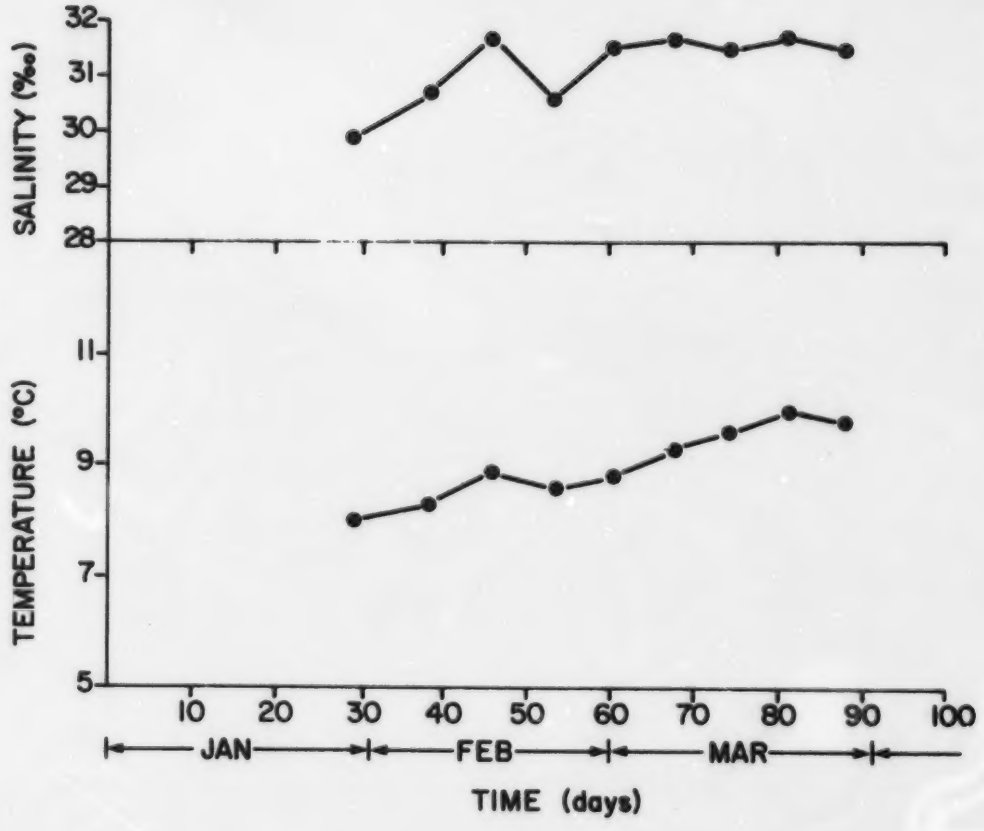


Fig. 2. Record of environmental conditions, February to April 1984, at the Whaleboat Passage impoundment site. Points are weekly means.

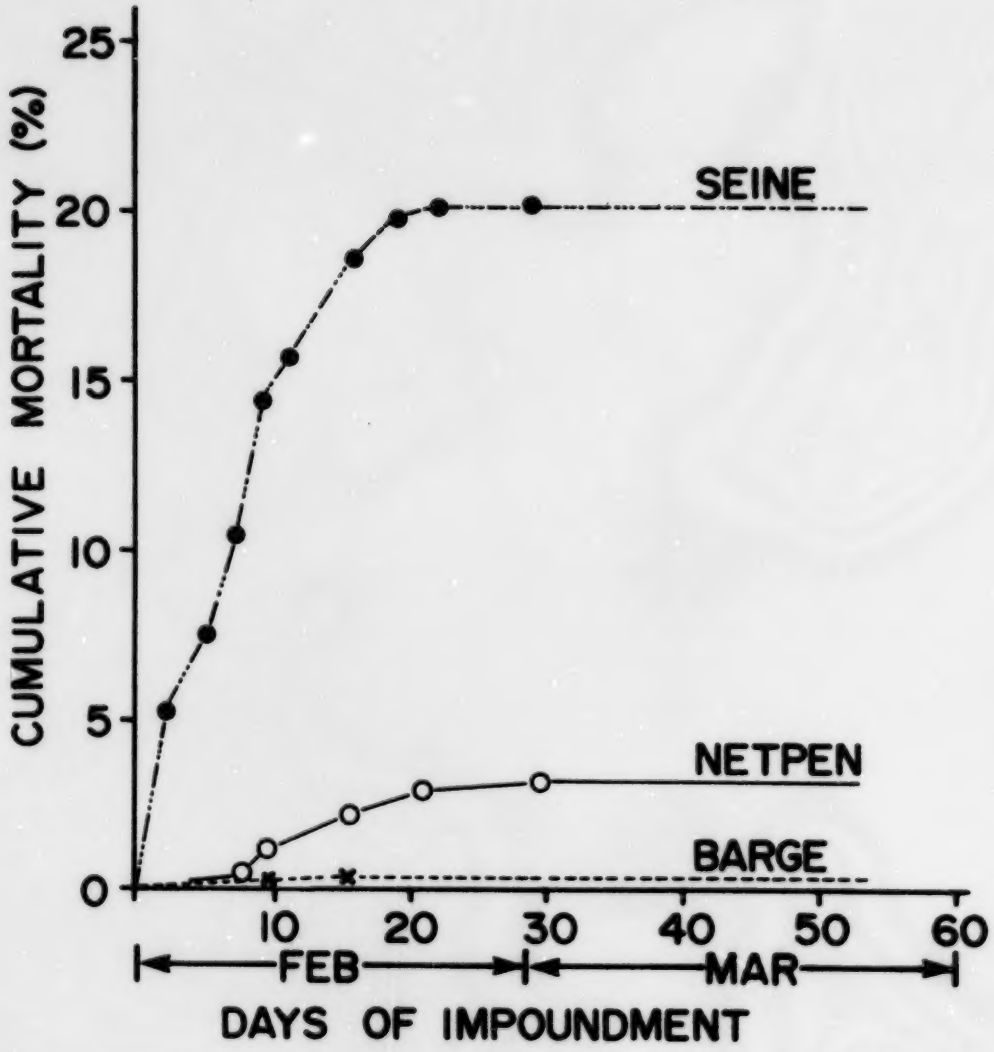
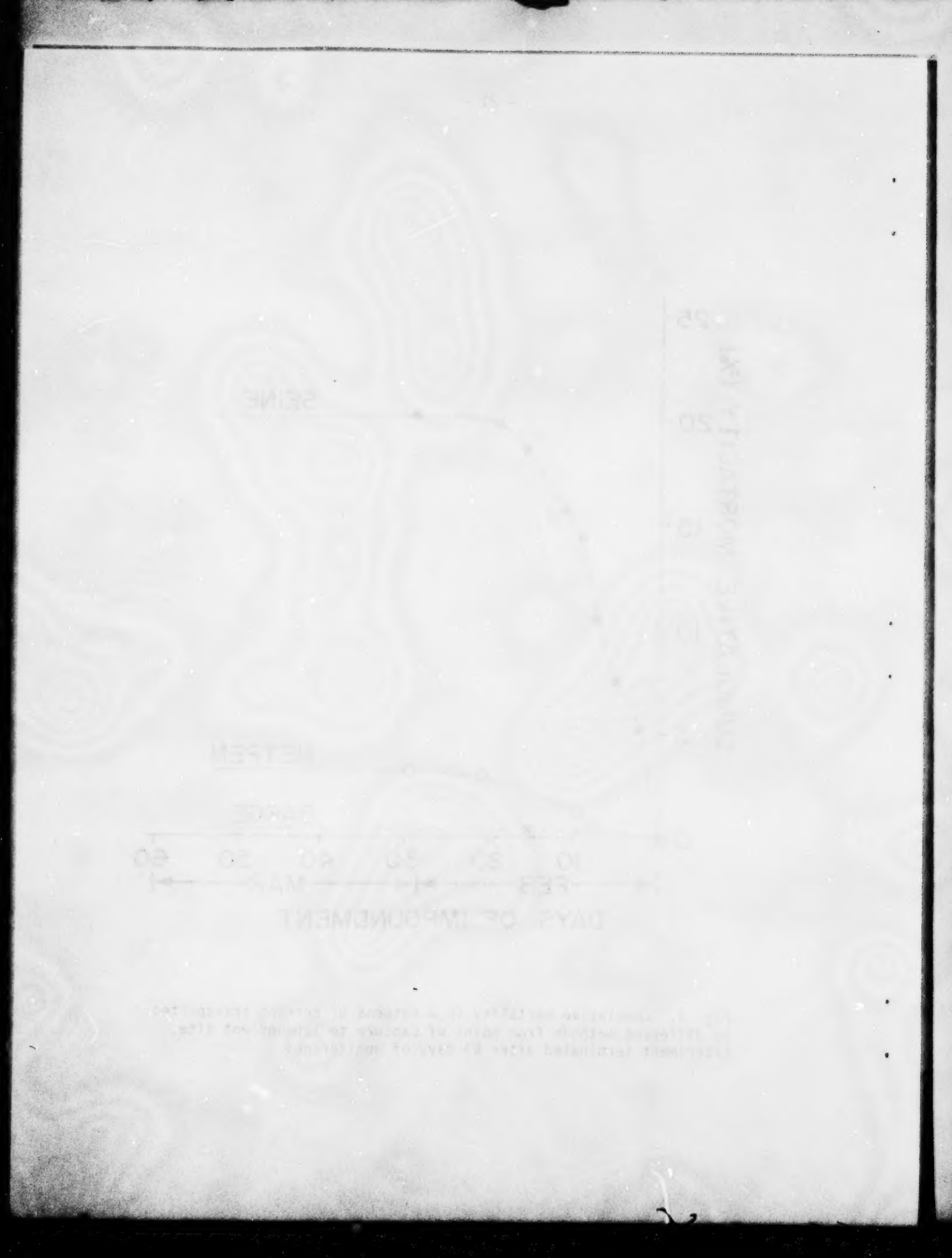


Fig. 3. Cumulative mortality in 3 netpens of herring transported by different methods from point of capture to impoundment site. Experiment terminated after 53 days of monitoring.



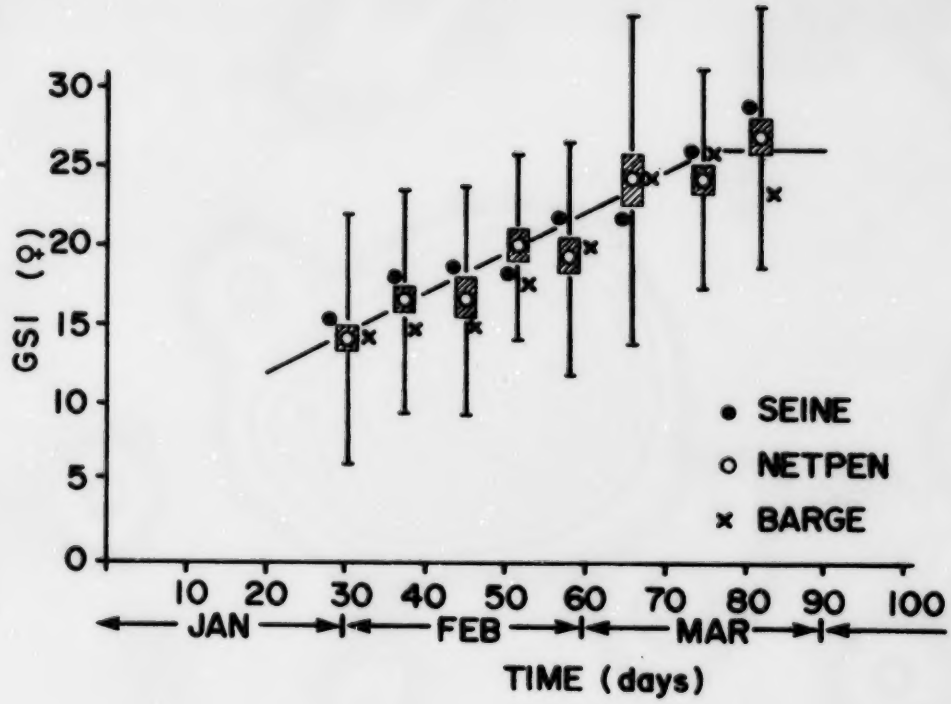
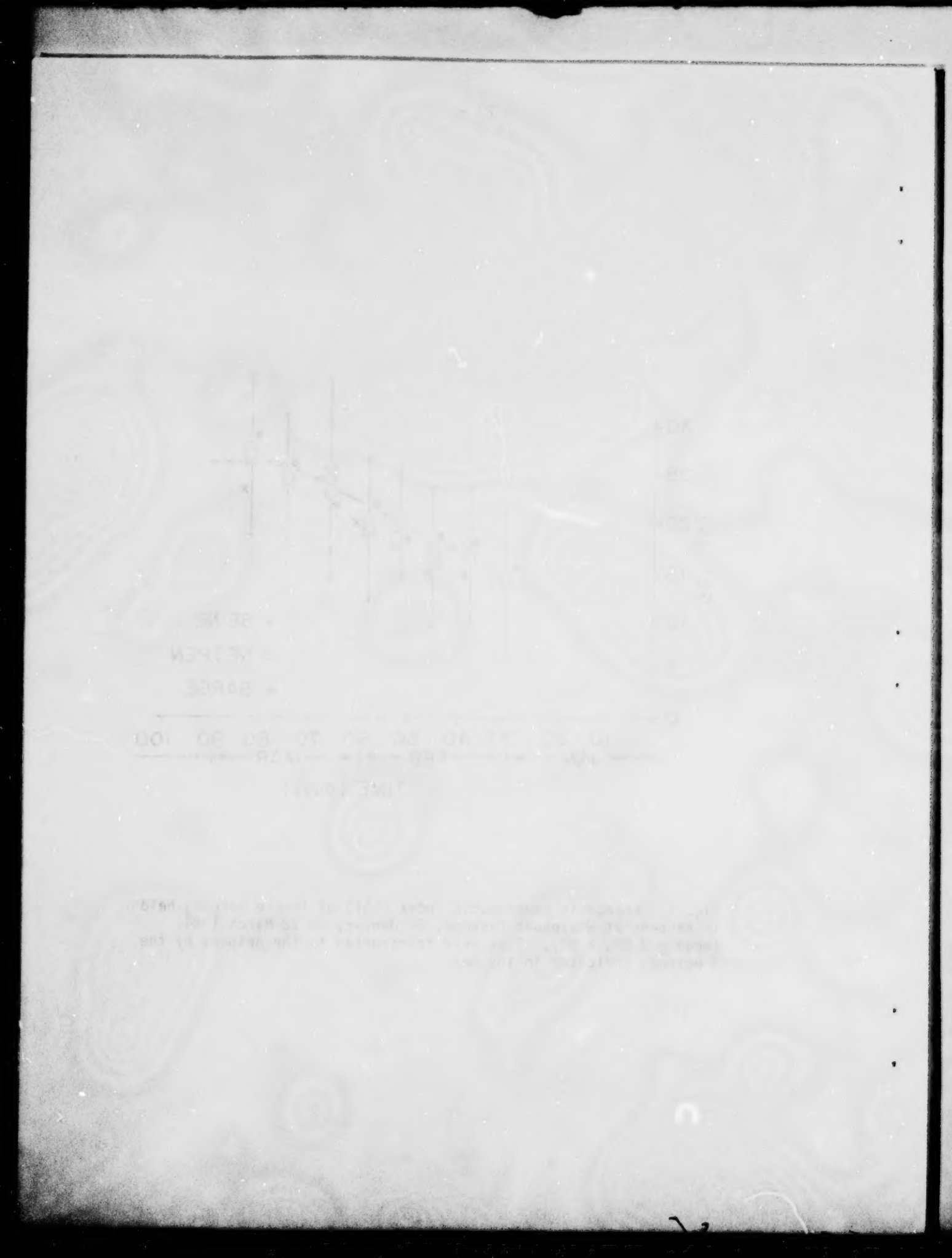


Fig. 4. Change in gonosomatic index (GSI) of female herring held in netpens at Whaleboat Passage, 30 January to 22 March 1984, (mean ± 2 SD, 2 SE). Fish were transported to the netpens by the 3 methods indicated in the key.



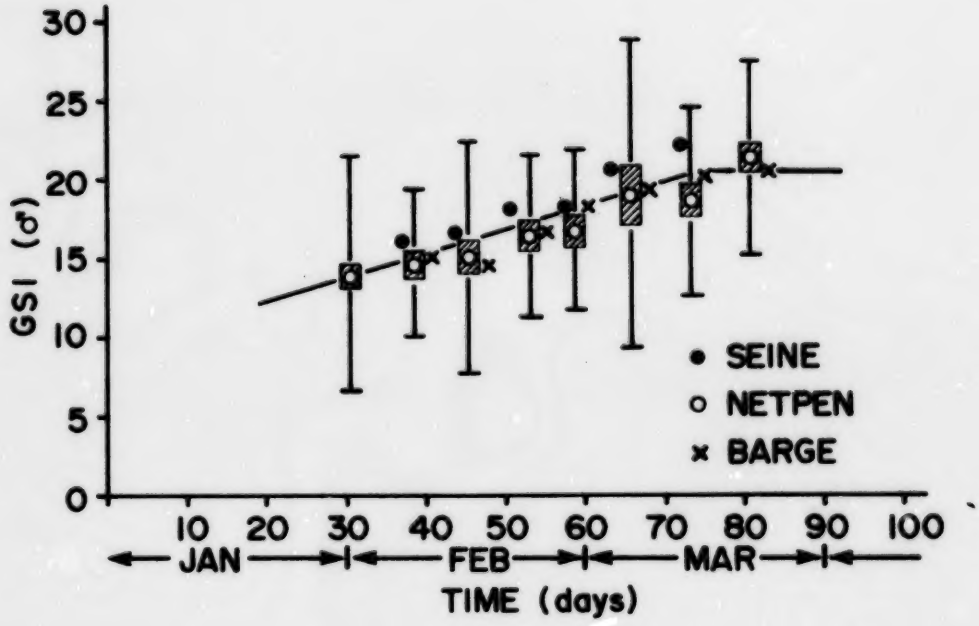
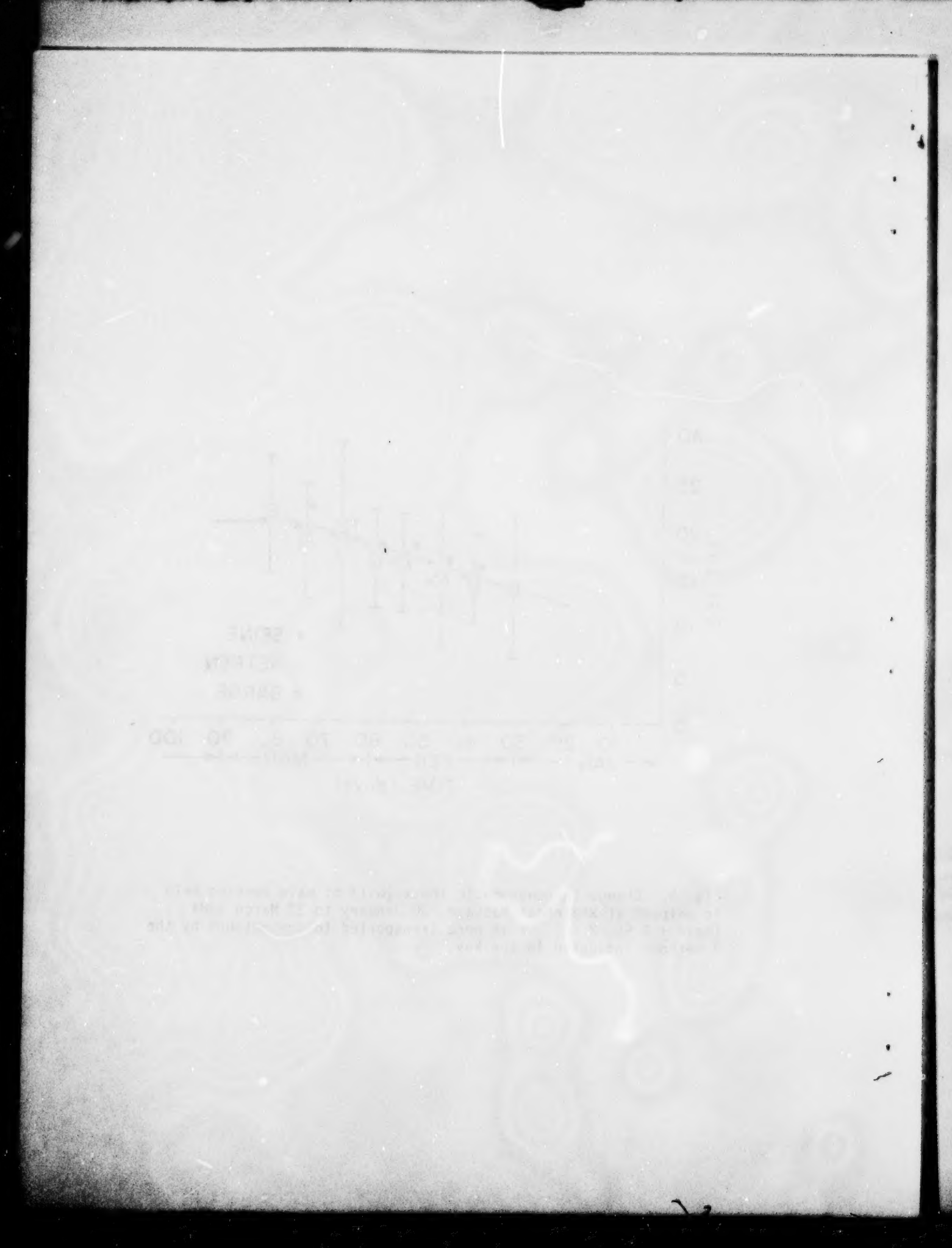


Fig. 5. Change in gonosomatic index (GSI) of male herring held in netpens at Whaleboat Passage, 30 January to 22 March 1984 (mean ± 2 SD, 2 SE). Fish were transported to the netpens by the 3 methods indicated in the key.



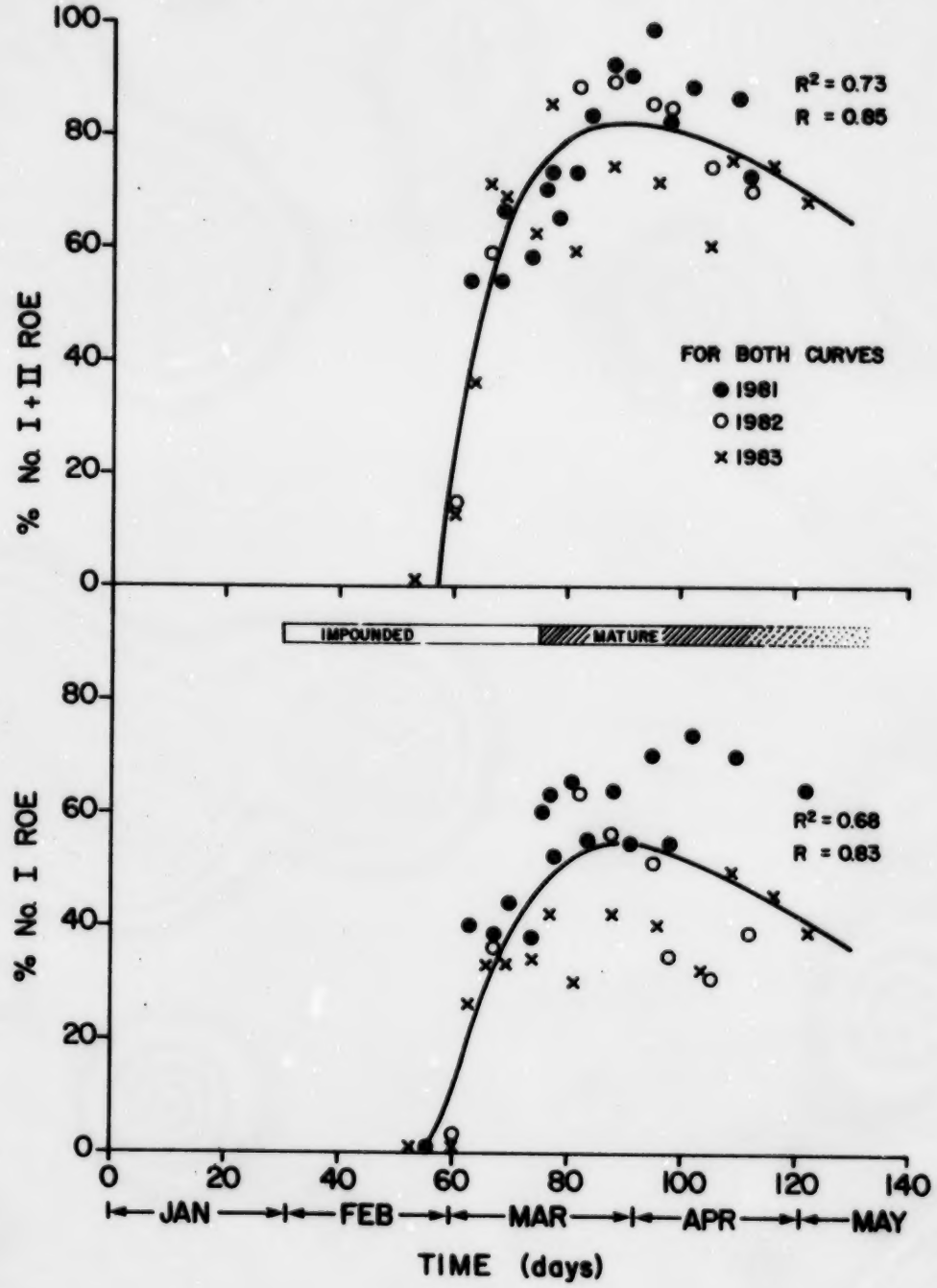
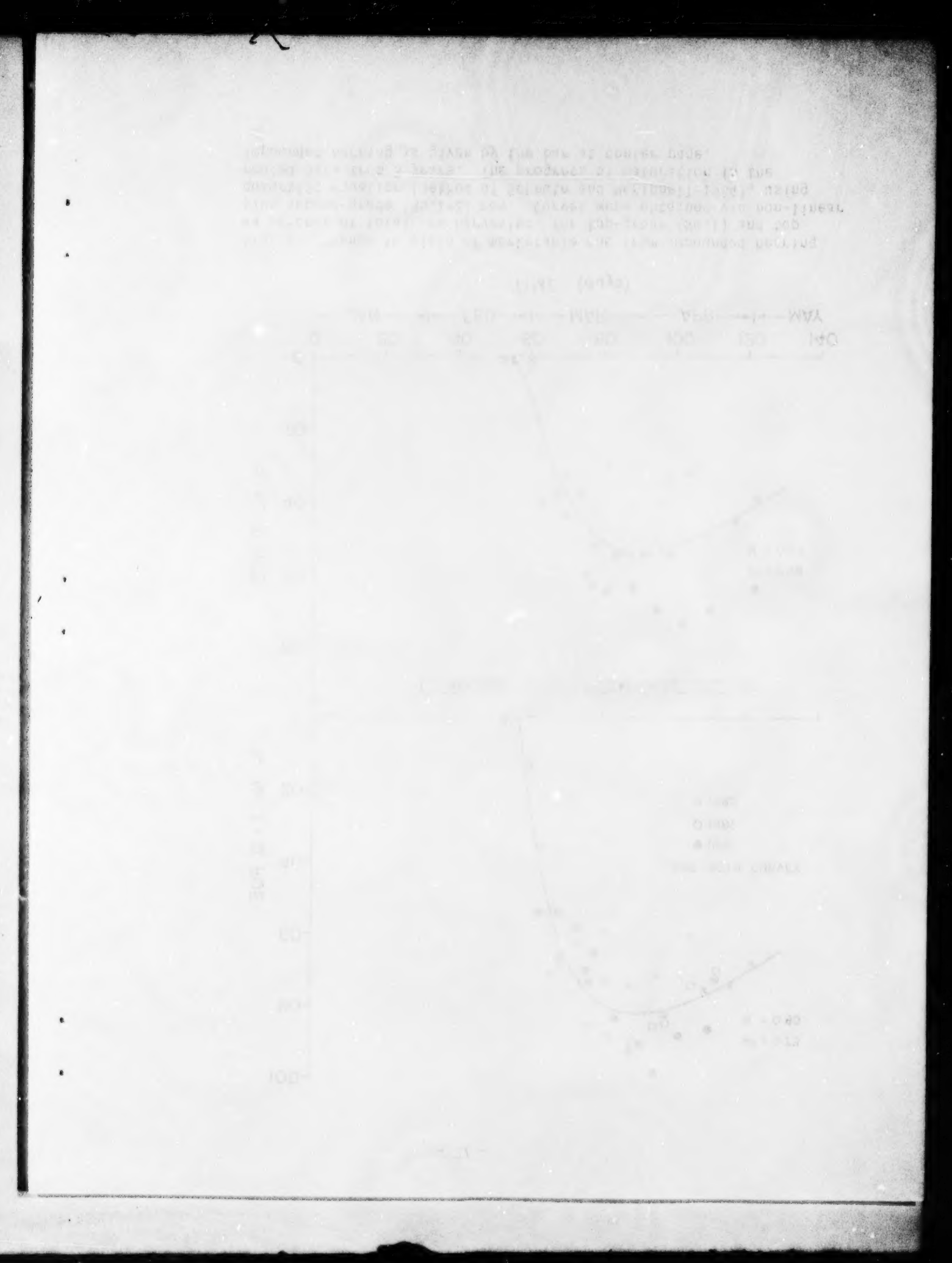


Fig. 6. Change in yield of marketable roe from impounded herring as percent of total roe harvested, for top-grade (No.1) and top plus second-grade (No.1+2) roe. Curves were obtained via non-linear quadratic equation (method of Schnute and McKinnell 1984), using pooled data from 3 years. The progress of maturation in the impounded herring is given by the bar at center page.



Appendix 1. Secondary processing method and criteria for quality assessment of roe from experimental impoundments.

Roe processing

Extracted roe is rinsed with water 2 or 3 times, depending on cleanliness, then placed in 10% brine and soaked overnight or for approximately 12 hours. After brief draining the roe is transferred to saturated brine (26 to 28%, w/v) for a day, changed to fresh brine once more if required, and extra salt is added to ensure that the roe is in saturated brine. The processed roe is then ready for grading and quality assessment after 5-7 days in saturated brine at 2-5 C.

Grading:

Grade 1:	Light yellow to yellowish brown in color, (no discoloration), full shape about 10 cm (4") long by 2.5 cm (1") wide, no off odor or bitter or rancid flavor
Grade 2:	Roe is between 6 and 9 cm (2.5-3.5"), medium size, full shape or broken
Grade 3:	Roe is under 6 cm (2.5"), small size, full shape or broken
Grade 4:	Irregular shape, or broken pieces under 4 cm (1.5")
Grade 5:	Unripe roe (immature)

Appendix 2. Example of how delay of harvest in an impoundment takes advantage of the continued increase in No.1 roe yield shown in Figure 6.

ROE YIELD AT HARVEST	CASE I
Day 75: 46.4% of all roe is No.1	Ideal opening (day 75)
Day 90: 54.4% " "	Hypothetical catch of 100 tons, GSI 25, 1:1 sex ratio, will yield 12.5 tons roe total. From curve, 46.4% is No.1, hence yield is 5.8 tons, processed.
Day 105: 49.8% " "	
Spawn date and GSI(max) at day 75, roe yield figures from curve in Figure 6 (dates from Julian calendar).	CASE II
	Impoundment
	Same catch as Case I, but harvested 15 days later on day 90, curve indicates yield of 54.4% No.1, i.e. yield after processing of 6.8 tons.

YIELD INCREASE: 6.8-5.8/5.8 = 17%

FACTORS:

1) Actual opening might have been premature, reducing actual roe yield below Case I level. Alternatively, catch may have comprised all large fish, giving a higher harvest of No. 1 roe.

2) There is a possibility that the impounded stock might spawn before harvest, however slight.

Appendix 3. Points used to plot percentage roe yields from a non-linear quadratic equation (see reference in text).

Julian Day	No. 1 roe	No. 1 + 2 roe
55	0.3	-
60	11.3	22.9
65	26.0	48.9
70	38.0	64.2
75	46.4	73.2
80	51.4	78.4
85	53.9	80.9
90	54.4	81.7
95	53.6	81.3
100	52.0	80.0
105	49.3	78.2
110	47.8	76.0
115	44.6	73.6
120	41.9	70.9
n	38	40